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Dietz

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[54] **FLUIDIZED BED COMBUSTION SYSTEM AND METHOD HAVING MULTIPLE FURNACE AND RECYCLE SECTIONS**

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[51] **Int. Cl.**[5] **F22B 1/00**

[52] **U.S. Cl.** ..... **122/4 D**; 110/245; 165/104.16; 422/141; 422/142; 422/146

[58] **Field of Search** ..... 122/4 D; 110/245; 165/104.16; 431/170; 422/141, 142, 146

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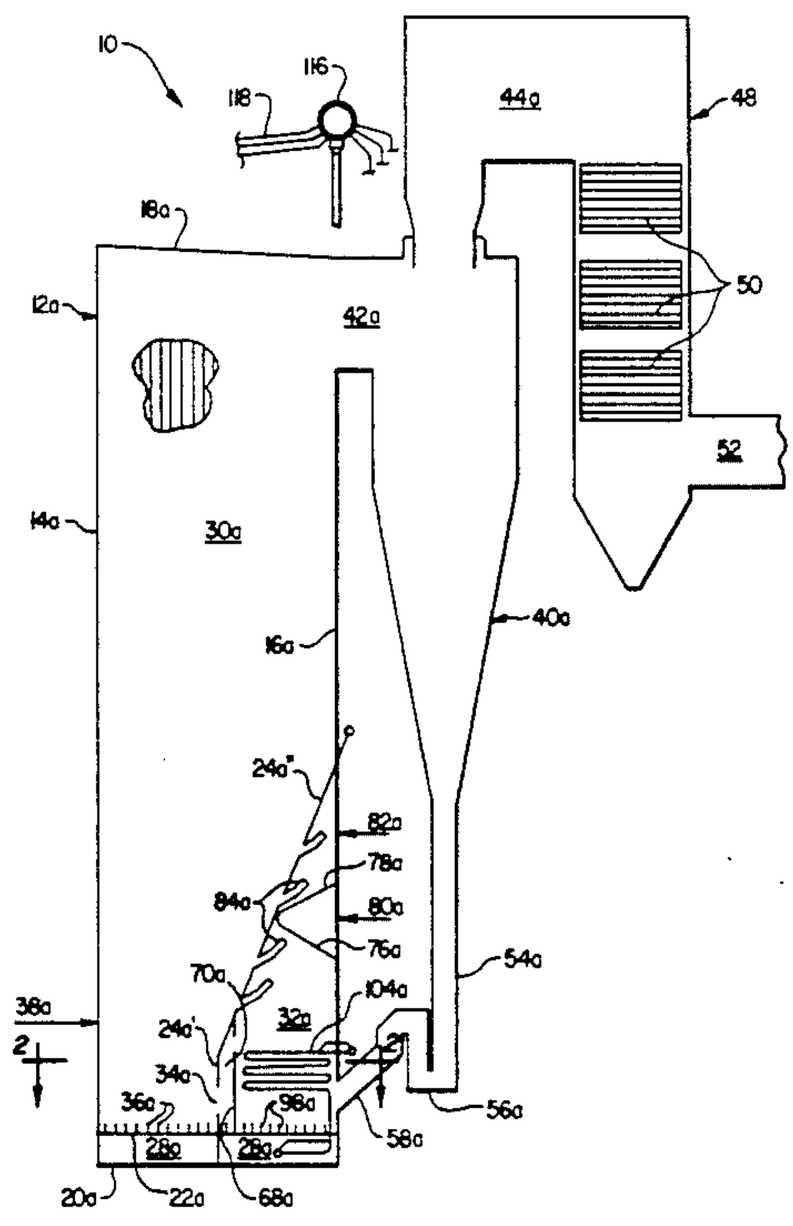
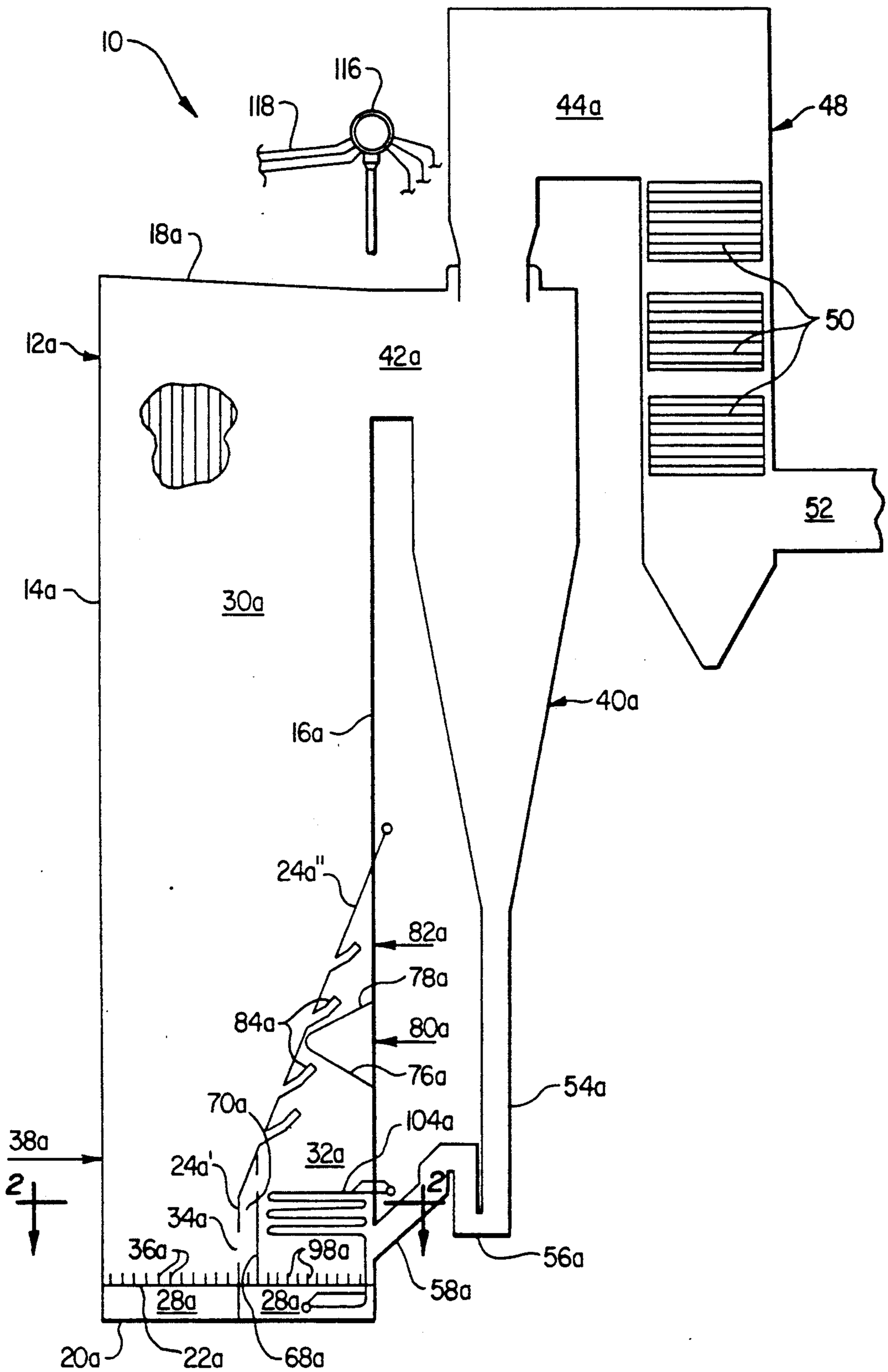
Primary Examiner—Edward G. Favors
Attorney, Agent, or Firm—Marvin A. Naigur

[57] **ABSTRACT**

A fluidized bed combustion system and method in which a plurality of enclosures, each having a furnace section and integral recycle section are joined using common walls. Openings are provided in lower portions of the common walls for permitting the fluidized bed material to flow between adjacent or opposing furnace sections and between adjacent recycle sections. Openings are also provided in upper portions of the common walls for equalizing the gas pressure between the adjacent or opposing furnace sections.

29 Claims, 5 Drawing Sheets

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118
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16a
40a
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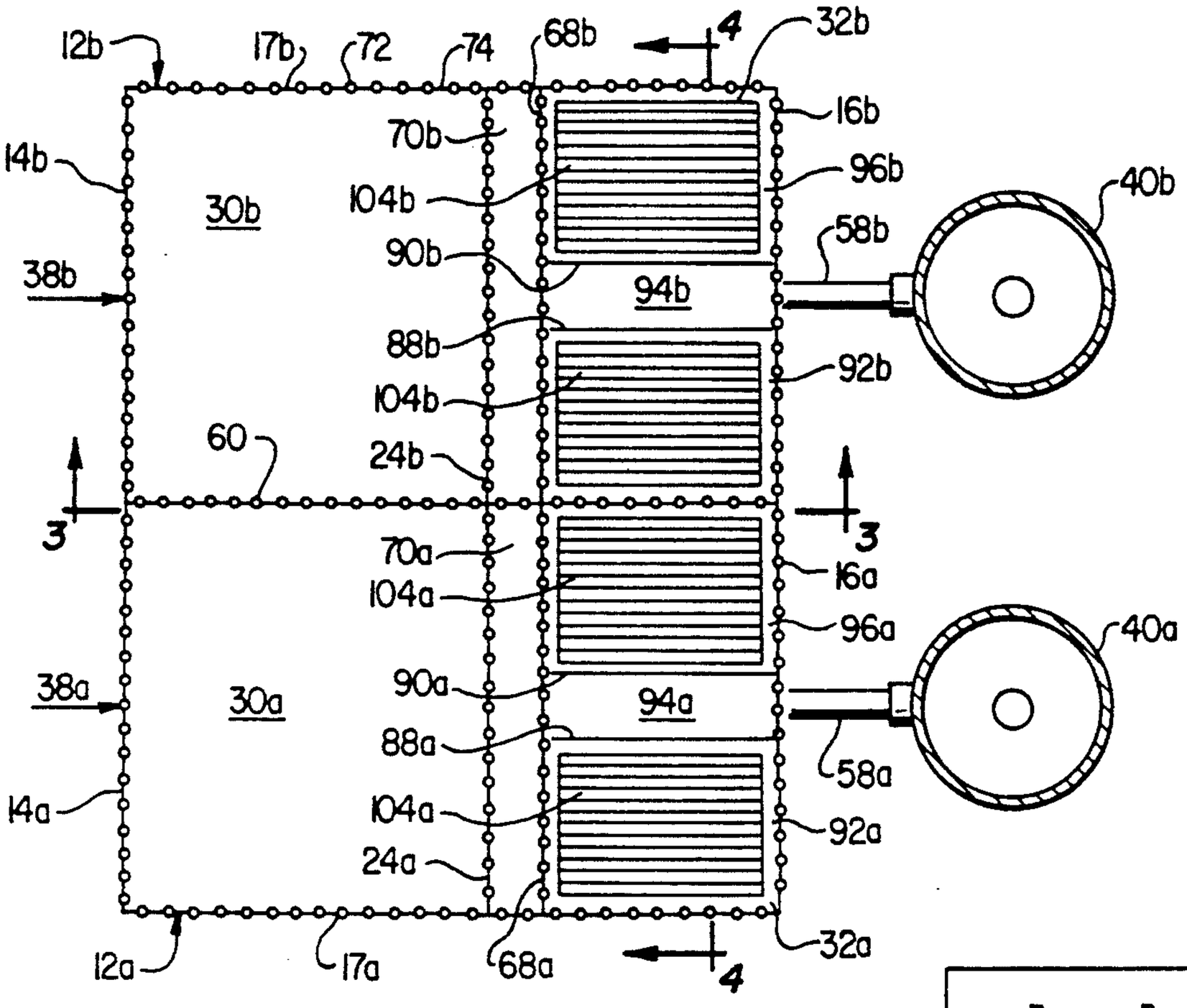
78a
84a
80a
76a
54a
70a
104a
38a
24a'
32a
2
2
34a
36a
98a
56a
58a
28a
28a
20a
22a
68a

FIG. 1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88b
92b
104b
60
24b
3
3
70a
16a
104a
96a
40a
38a
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12a
17a
68a
4
32a

FIG. 2

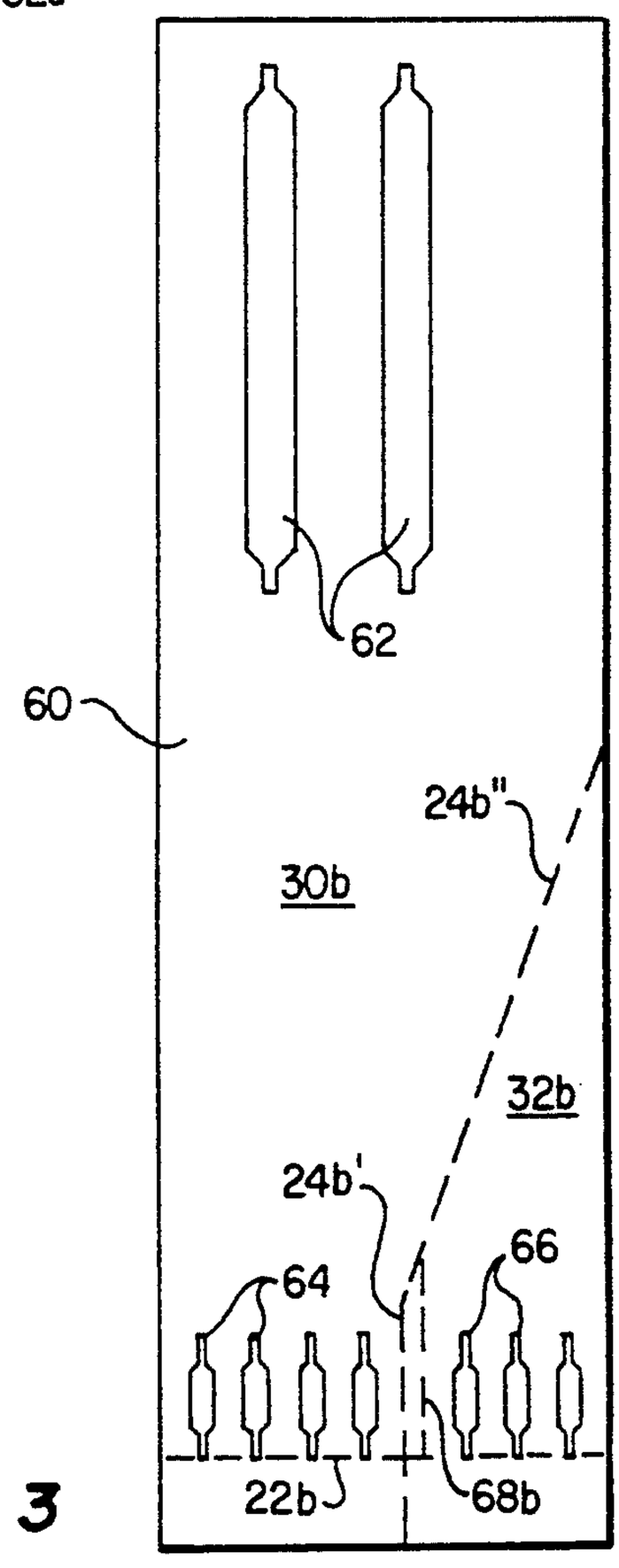
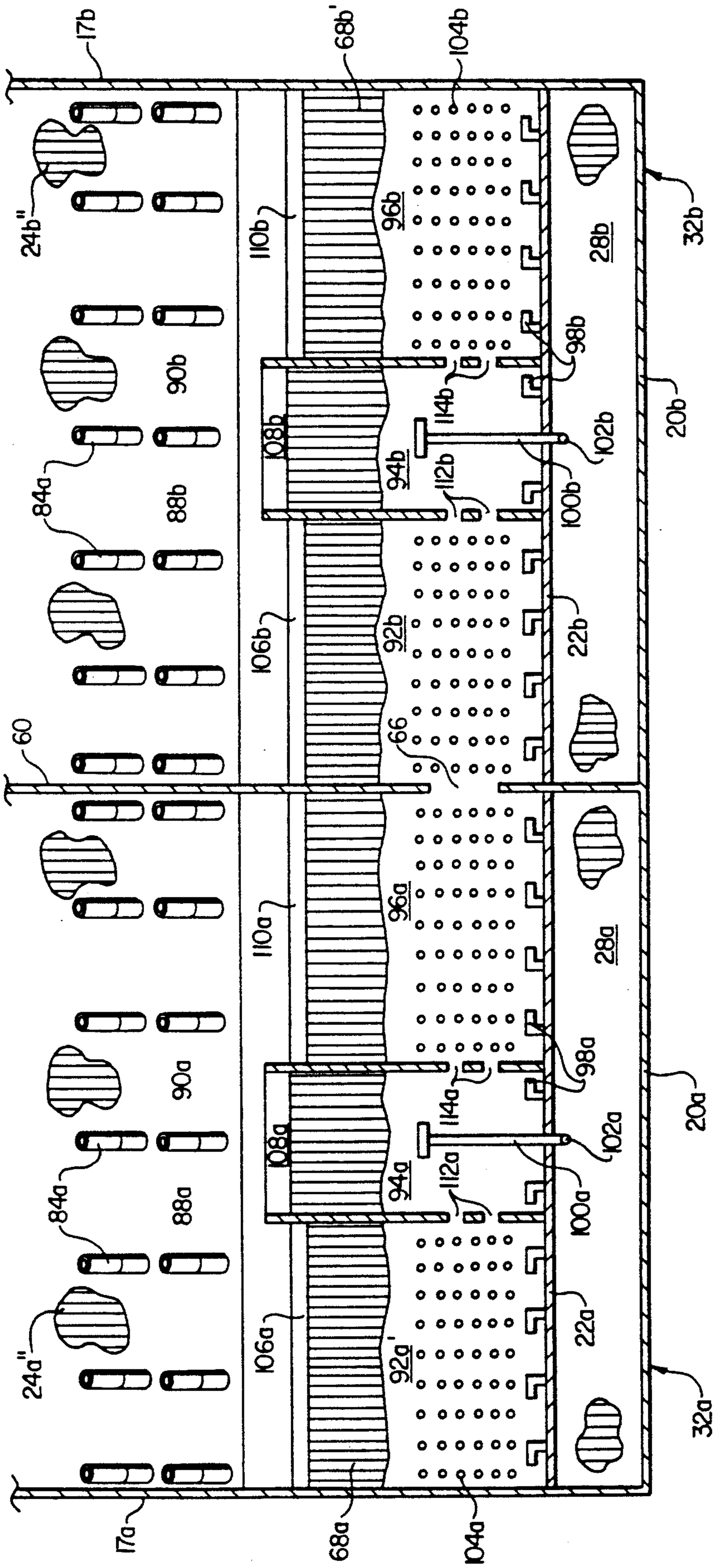

62
60
24b"
30b
32b
24b'
64
66
22b
68b

FIG. 3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68b'
104b
24b"
110b
96b
28b
32b
90b
84a
88b
108b
94b
114b
112b
98b
102b
100b
20b
106b
92b
22b
60
66
110a
96a
28a
90a
84a
88a
108a
94a
114a
112a
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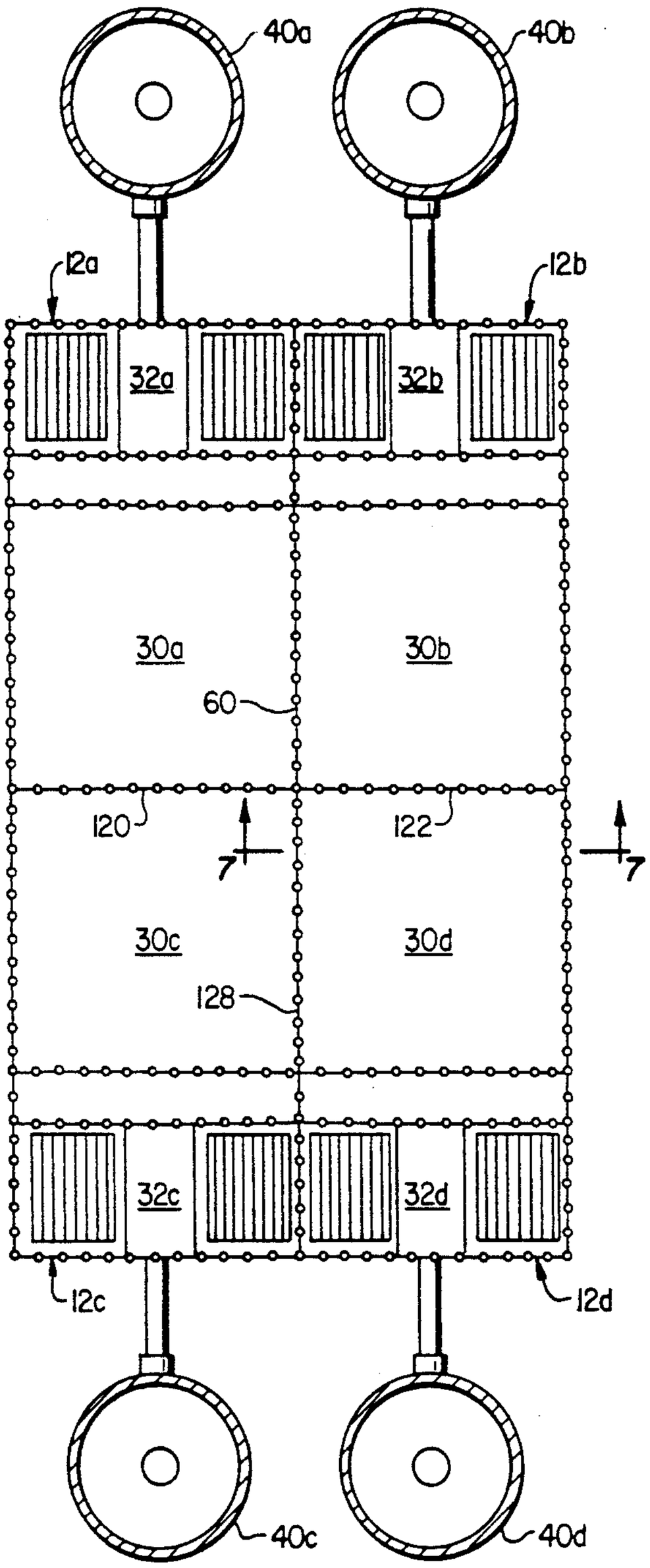
100a
20a
24a"
106a
92a'
22a
32a
17a
68a
104a

FIG. 4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40b
12a
12b
32a
32b
30a
30b
60
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122
7
7
30c
30d
128
32c
32d
12c
12d
40c
40d

FIG. 5

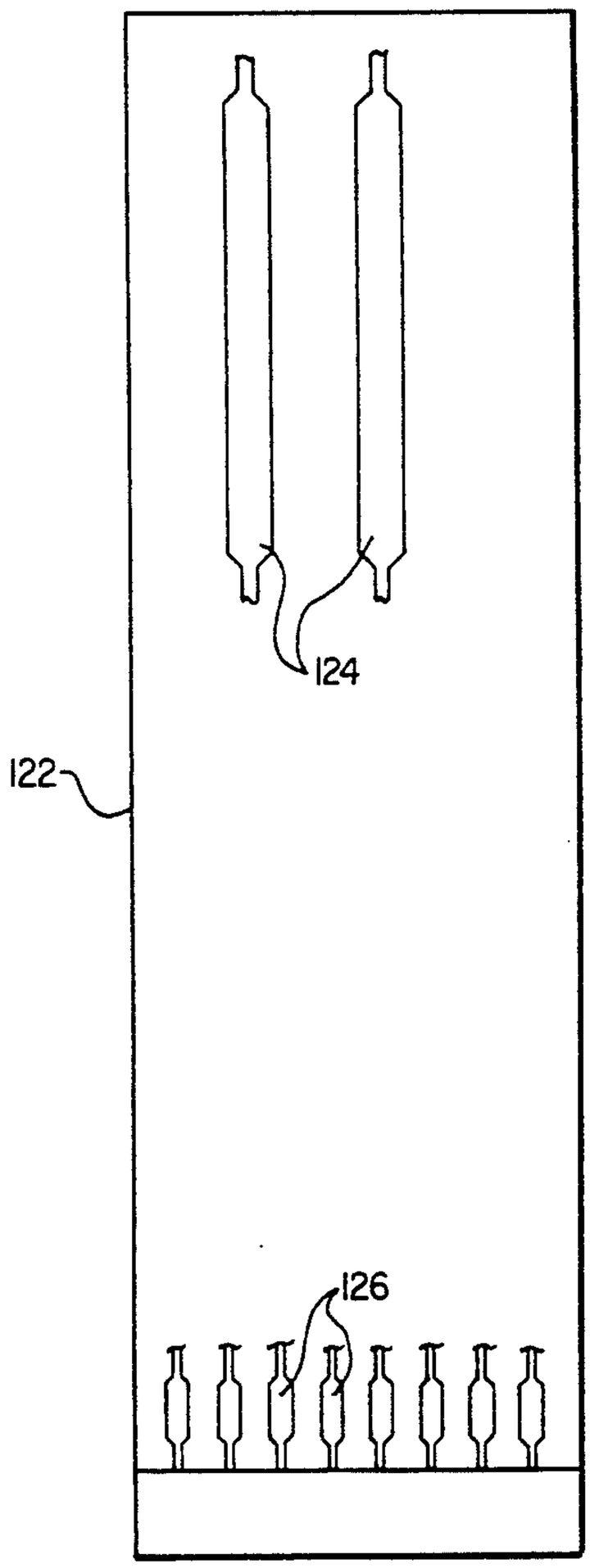
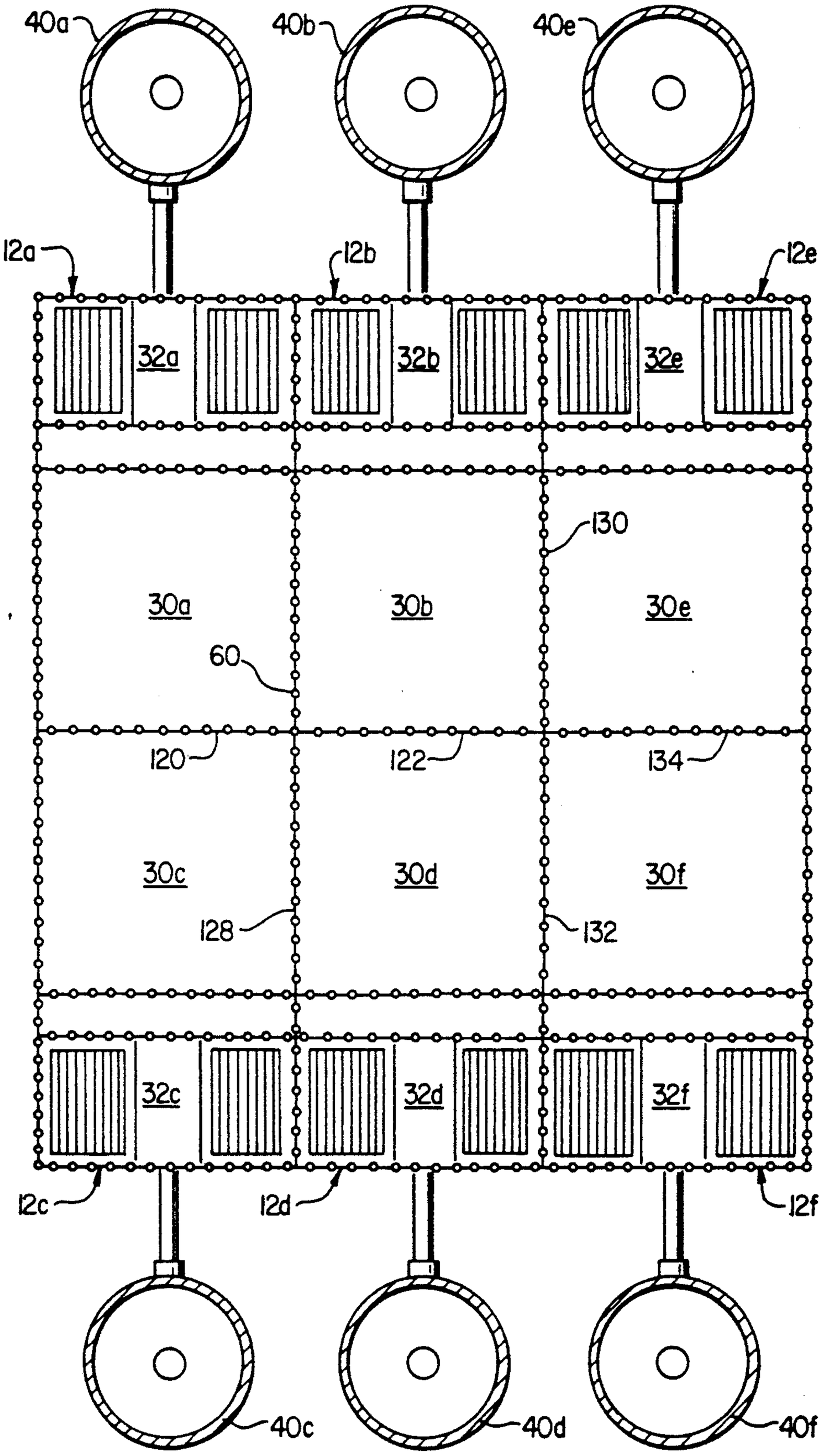

124
122
126

FIG. 7


40a
40b
40e
12a
12b
12e
32a
32b
32e
130
30a
30b
30e
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120
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134
30c
30d
30f
128
132
32c
32d
32f
12c
12d
12f
40c
40d
40f

FIG. 6

FLUIDIZED BED COMBUSTION SYSTEM AND METHOD HAVING MULTIPLE FURNACE AND RECYCLE SECTIONS

BACKGROUND OF THE INVENTION

This invention relates to a combustion system and method, and, more particularly, to such a system and method in which a plurality of adjacent and opposing enclosures including furnace sections and recycle sections are provided for receiving fluidized beds.

Fluidized bed combustion systems are well known and include a furnace section in which air is passed through a bed of particulate material, including a fossil fuel, such as coal, and a sorbent for the oxides of sulfur generated as a result of combustion of the coal, to fluidize the bed and to promote the combustion of the fuel at a relatively low temperature. These types of combustion systems are often used in steam generators in which water is passed in a heat exchange relationship to the fluidized bed to generate steam and permit high combustion efficiency and fuel flexibility, high sulfur adsorption and low nitrogen oxides emissions.

A typical fluidized bed utilized in the furnace section of these type systems is commonly referred to as a "bubbling" fluidized bed in which the bed of particulate material has a relatively high density and a well defined, or discrete, upper surface. Other types of systems utilize a "circulating" fluidized bed in which the fluidized bed density is below that of a typical bubbling fluidized bed, the fluidizing air velocity is equal to or greater than that of a bubbling bed, and the flue gases passing through the bed entrain a substantial amount of the fine particulate solids to the extent that they are substantially saturated therewith.

Circulating fluidized beds are characterized by relatively high internal and external solids recycling which makes them insensitive to fuel heat release patterns, thus minimizing temperature variations and, therefore, stabilizing the sulfur emissions at a low level. The external solids recycling is achieved by disposing a cyclone separator at the furnace section outlet to receive the flue gases, and the solids entrained thereby, from the fluidized bed. The solids are separated from the flue gases in the separator and the flue gases are passed to a heat recovery area while the solids are recycled back to the furnace. This recycling improves the efficiency of the separator, and the resulting increase in the efficient use of sulfur adsorbent and fuel residence time reduces the adsorbent and fuel consumption. U.S. Pat. Nos. 5,040,492 and 5,054,436, assigned to the same assignee as the present application, disclose systems in which the separated solids are recycled back to the furnace.

U.S. Pat. Nos. 4,609,623 and 4,809,625, assigned to the same assignee as the present application, disclose a fluidized bed reactor in which a dense, or bubbling, bed is maintained in the lower portion of the furnace, while the bed is otherwise operated as a circulating bed. This hybrid arrangement results in several advantages not the least significant of which is the ability to utilize fuel and adsorbent over a relatively large particle size range.

In designing fluidized bed combustion systems of the above types, increases in furnace capacity from a given design are usually achieved by increasing the height of the furnace walls. However, this is expensive and there are certain limits to the height of the walls. It has therefore been suggested that the size of the furnace, and therefore its capacity, be increased by increasing the

size of the furnace in "plan view" i.e., increasing the width and/or the depth of the furnace. However, this usually requires a common wall, or the like, to be placed in the furnace section to divide the area into two or more fluidized beds which requires separate operating controls, etc. which is expensive. Also, the common wall is subjected to lateral loading, especially when the multiple beds operate differently or if one bed is rendered inoperable due to equipment failure. This lateral loading can cause damage to the wall and attendant reduction i operation and efficiency.

Increases in furnace capacity also lead to the use of larger cyclone separators which permit increasing amounts of fine, unburnt fuel particles to escape with the separated flue gases. This escape of unburnt fuel particles reduces fuel efficiency, thereby increasing fuel consumption.

SUMMARY OF THE INVENTION

It is therefore an object of the present invention to provide a fluidized bed combustion system and method which has an increased capacity without any increase in furnace wall height.

It is a further object of the present invention to provide a fluidized bed combustion system and method of the above type in which two or more separate enclosures having furnace sections are provided.

It is a further object of the present invention to provide a fluidized bed combustion system and method of the above type in which two or more enclosures having furnace sections and integral recycle sections are provided.

It is a further object of the present invention to provide a fluidized bed combustion system and method of the above type in which the enclosures are joined by common walls.

It is a still further object of the present invention to provide a fluidized bed combustion system and method of the above type in which separate furnace sections may be operated without the need for separate controls.

It is a still further object of the present invention to provide a fluidized bed combustion system and method of the above type in which separate integral recycle sections may be operated without the need for separate controls.

It is a still further object of the present invention to provide a fluidized bed combustion system and method of the above type in which the common walls are vented to equalize the pressure across the walls, to minimize or eliminate lateral loading and to enable the fluidized beds in each furnace section to maintain substantially the same height.

It is a still further object of the present invention to provide a fluidized bed combustion system and method of the above type in which the common walls are vented to enable the fluidized beds in the integral recycle sections to maintain substantially the same height.

It is a still further object of the present invention to provide a fluidized bed combustion system and method of the above type in which fuel efficiencies are increased by reducing losses of fine, unburnt fuel particles.

Toward the fulfillment of these and other objects, according to the system and method of the present invention a plurality of enclosures, each having a furnace section and a recycle section, are joined using common walls A fluidized bed of particulate material is

formed in each furnace section and recycle section and the flue gases in each furnace section entrain portions of the particulate material and rise upwardly in each furnace section before discharging to a cyclone separator or the like. Upper and lower portions of the common walls are vented to equalize pressure across the walls and to maintain substantially identical dense bed heights in the furnace sections and substantially identical dense bed heights in the recycle sections.

BRIEF DESCRIPTION OF THE DRAWINGS

The above brief description, as well as further objects, features and advantages of the present invention will be more fully appreciated by reference to the following detailed description of the presently preferred but nonetheless illustrative embodiments in accordance with the present invention when taken in conjunction with the accompanying drawings wherein:

FIG. **1** is a schematic representation depicting the system of the present invention;

FIG. **2** is an enlarged cross-sectional view taken along the line **2—2** of FIG. **1**;

FIG. **3** is a reduced cross sectional view taken along the line **3—3** of FIG. **2**;

FIG. **4** is a cross-sectional view taken along the line **4—4** of FIG. **2**; and

FIGS. **5** and **6** are views similar to FIG. **2** but depicting alternate embodiments of the system of the present invention.

FIG. **7** is an enlarged cross-sectional view taken along the line **7—7** of FIG. **5**.

DESCRIPTION OF THE PREFERRED EMBODIMENT

Referring to FIGS. **1** and **2** of the drawings, the fluidized bed combustion system of the present invention is referred to in general by the reference numeral **10**. The system **10** includes two upright water-cooled enclosures **12***a* and **12***b* which are substantially identical. For the convenience of presentation, only enclosure **12***a* will be described in detail.

The enclosure **12***a* has a front wall **14***a*, a rear wall **16***a* and two sidewalls, one of which is referred to by the reference numeral **17** and the other of which is formed by a common wall extending between the enclosures **12***a* and **12***b*, which will be discussed in detail later. The upper portion of the enclosure **12***a* is closed by a roof **18***a* and the lower portion includes a floor **20***a*. A distribution plate or grate **22***a* extends across a lower portion of the enclosure **12***a*. The plate **22***a* is spaced from the floor **20***a* to define a plenum area between the floor **20***a* and the plate **22***a* which is adapted to receive an oxygen-containing gas such as air from an external source (not shown).

A partition **24***a* is disposed in the enclosure **12***a* and extends between the side walls, including side wall **17***a*. The partition **24***a* includes a lower, substantially vertical portion **24***a'* which extends upwardly from the floor **20***a*, through the distribution plate **22***a*, and into the enclosure **12***a*. The partition portion **24***a'* is disposed parallel to the front and rear walls **14***a* and **16***a*. The partition **24***a* also includes an upper portion **24***a''* which angles upwardly and rearwardly from the lower portion **24***a'* of the partition to the rear wall **16***a*. The partition **24***a* thereby divides the plenum area into plenum chambers **26***a* and **28***a* and further divides the enclosure **12***a* into a furnace section **30***a* disposed above plenum chamber **26***a* and a recycle section **32***a* disposed above plenum chamber **26***a*. At least one opening **34***a* is provided in a lower portion of the vertical partition portion **24***a'* for reasons to be described. A plurality of air distributor nozzles **36***a* are mounted in corresponding openings formed in the portion of the plate **22***a* extending under the furnace section **30***a* for passing air through the plate **22***a*, for reasons to be described.

A feeder system **38***a* is provided adjacent the front wall **14***a* for introducing particulate material into the furnace section **30***a*. The particulate material includes fuel and may also include other components including an adsorbent, such as limestone.

The particulate material is fluidized in the furnace section **30***a* by the air from the plenum **26***a* as it passes upwardly through the plate **22***a*. This air promotes the combustion of the fuel, generating combustion gases which combine with the air to form flue gases which rise in the furnace section **30***a* by convection and which entrain a portion of the particulate material as will be described.

A cyclone separator **40***a* extends adjacent the enclosure **12***a*. As shown in FIG. **1**, a duct **42***a* extends from an outlet opening provided in the rear wall **16***a* of the enclosure **12***a* to an inlet opening provided through the wall of the separator **40***a*. The separator **40***a* receives flue gases and entrained particulate material from the furnace section **30***a* in a manner to be described and operates in a conventional manner to disengage the particulate material from the flue gases. The separated flue gases in the separator, which are substantially free of solids, pass, via a duct **44***a* located immediately above the separator, into a heat recovery section **48**, via an inlet provided through a wall thereof.

The heat recovery section **48** includes a plurality of heat exchange surfaces **50** which may serve as heaters, reheaters, superheaters, and economizers, all of which are formed by a plurality of heat exchange tubes extending in the path of the gases as they pass through the heat recovery section **48**. After passing across the heat exchange surfaces **50**, the gases exit the heat recovery section **48** through an outlet **52**. It is preferred that a number of separators associated with additional enclosures be connected to a single heat recovery section **48**. It is understood that a number of different embodiments of heat recovery sections may be used. For a more detailed discussion of a preferred embodiment of a heat recovery section, see U.S. Pat. Nos. 5,040,492 and 5,054,436, both assigned to the assignee of the present invention. The disclosure of these references is incorporated herein by reference.

As shown in FIG. **1**, the lower portion of the separator **40***a* is conically shaped and is connected to a dip leg **54***a* which, in turn, is connected to a J-valve **56***a*. A conduit **58***a* connects the outlet of the J valve **56***a* to the recycle section **32***a* to transfer the separated particulate material from the separator **40***a* to the recycle section **32***a*. The J valve **56***a* functions in a conventional manner to prevent back-flow of solids from the furnace section **30***a* and the recycle section **32***a* to the separator **40***a*. It is understood that a substantially identical separator, dip leg, J-valve and inlet conduit are associated with each enclosure and all function in a substantially identical fashion. It is also understood that other types of separators may be used, and the separators may pass the separated particulate material to the recycle sections in any conventional manner.

As shown in FIG. **2**, the enclosures **12***a* and **12***b* are disposed adjacent one another and share a common wall

60 which extends from front walls 14*a* and 14*b* to rear walls 16*a* and 16*b* and which extends from the enclosure floors 20*a* and 20*b* to the enclosure roofs, including roof 18*a*. A furnace section 30*b* is formed in the enclosure 12*b* and is disposed adjacent the furnace section 30*a*, and a recycle section 32*b* located adjacent the furnace section 30*b* and is disposed adjacent the recycle section 32*a*.

As shown in FIG. 3, a plurality of openings 62 are provided in the upper portion of the common wall 60 and a plurality of openings 64 and 66 are provided in the lower portion of the common wall 60, for reasons to be described.

FIGS. 2 and 4 depict the adjacent recycle sections 32*a* and 32*b* in greater detail. For convenience of presentation, the recycle section 32*a* will be described in detail, it being understood that the description also applies to the recycle section 32*b*, as well as to additional recycle sections such as those in FIGS. 5 and 6.

A partition 68*a* is disposed in the recycle section 32*a* and extends between the side wall 17*a* and the common wall 60 and parallel to the vertical partition portion 24*a'*. The partition 68*a* also extends from the distribution plate 22*a* to the angled portion 24*a''* of the partition 24*a* to define a channel 70*a* between the partitions 24*a* and 68*a*. A plurality of openings are provided in an upper portion of the partition 68*a* for reasons to be described.

The front wall 14*a*, the rear wall 16*a*, the sidewalls, the roof 18*a*, the partitions 24*a* and 68*a*, and the walls of the separator 40*a* and heat recovery section 48 are all formed by a plurality of vertically-extending, spaced, parallel tubes 72 with adjacent tubes being connected by continuous fins 74 along their lengths to form airtight structures. As shown schematically in FIG. 1, a portion of the tubes 72 forming the rear wall 16*a* are bent out of the plane of the latter wall, towards the partition section 24*a''* to form a partition 76*a*, and back to the rear wall 16*a* to form a partition 78*a*. The partitions 76*a* and 78*a* thus help support the partition section 24*a''*.

A pair of vertically-spaced secondary air inlets 80*a* and 82*a* register with openings in the rear wall 16*a* for introducing a secondary, oxygen-containing gas such as air into the enclosure 12*a* at two levels, one between the points of intersection of the partitions 76*a* and 78*a* with the rear wall 16*a* and another above the point of intersection of the partition 78*a* with the rear wall 16*a*. Although not clear from the drawings, it is understood that the tubes 72 forming the partition 76*a* have no fins so that secondary air from the inlet 80*a* can pass therethrough, while the tubes 72 forming the partition 78*a* are finned to prevent the passage of air therethrough and thus form a roof for the recycle section 32*a*.

As shown in FIG. 1, four rows of nozzles 84*a* extend through the partition portion 24*a''*, with two rows located above the partition 78*a* and two rows located below the partition 78*a*. As a result, secondary air from the inlet 80*a* is directed through the lower two rows of nozzles 84*a*, and secondary air from the inlet 82*a* is directed through the upper two rows of nozzles 84*a*.

As best shown in FIGS. 2 and 4, partitions 88*a* and 90*a* are disposed within the recycle section 32*a* and extend between the rear wall 16*a* and the partition 68*a*, substantially parallel to the side wall 17*a* and the common wall 60. The partitions 88*a* and 90*a* extend upwardly from the distribution plate 22*a* to a desired height within the recycle section 32*a*. Referring to FIG. 4, the partitions 88*a* and 90*a* divide the lower portion of the recycle section 32*a* into three compartments 92*a*, 94*a* and 96*a*. As shown in FIG. 2, the inlet conduit 58*a* registers with an opening in the rear wall 16*a* communicating with the compartment 94*a*.

Within the recycle section 32*a*, a plurality of rows of nozzles 98*a* extend through the perforations in the plate 22*a* above plenum chamber 28*a*. Each nozzle 98*a* consists of a central portion extending through the perforation and a horizontal discharge portion registering with the vertical portion. The nozzles 98*a* in the compartments 92*a* and 96*a* are disposed in parallel rows with their discharge portions facing away from the compartment 94*a*. Two parallel rows of nozzles 98*a* are provided in the compartment 94*a* with their discharge portions facing towards the partitions 88*a* and 90*a*, respectively. A single row of nozzles 100*a* is also located in the compartment 94*a* and extends between the two rows of nozzles 98*a*. The nozzles 100*a* are taller than the nozzles 98*a* for reasons to be explained. A manifold 102*a* is located in the plenum 28*a* and is connected to the nozzles 100*a* for supplying air to the nozzles 100*a* independently of the flow of air from the plenum 28*a*, through the plate 22 and to the nozzles 98*a*.

As shown in FIG. 4, a bank of heat exchange tubes 104*a* are disposed in each of the compartments 92*a* and 96*a*. The tubes 104*a* are bent into a serpentine pattern and extend between headers for circulating fluid through the tubes 104*a* in a conventional manner.

Three horizontally-spaced, elongated slots or openings 106*a*, 108*a* and 110*a* (FIG. 4) are provided through a portion of the partition 68*a* defining the compartments 92*a*, 94*a* and 96*a*, respectively. The opening 108*a* extends at an elevation higher than the openings 106*a* and 110*a* for reasons to be described. The openings are shown schematically in FIG. 4 for the convenience of presentation, it being understood that they actually are formed by cutting away the fins 74, or bending the tubes 72 out of the plane of the partition 68*a*. A plurality of openings 112*a* and 114*a* are formed in the lower portions of the partitions 88*a* and 90*a*, respectively, to communicate the chambers 92*a* and 96*a* with the chamber 94*a*. As shown in FIG. 2, the common wall 60 extends to the rear wall 16*a* to separate the recycle sections 32*a* and 32*b* and a plurality of openings 66 are provided in the extended portion of the common wall 60, for reasons to be described.

It is understood that the particular design of recycle sections 32*a* and 32*b* is shown as an example only and that a number of different embodiments of recycle sections may be used. For example, U.S. Pat. Nos. 5,054,436 and 5,040,492, both assigned to the assignee of the present application, disclose a number of different recycle section configurations that may be employed with the present invention. The disclosure of these references is incorporated herein by reference.

It is understood that the above description of the disclosure 12*a* is equally applicable to the enclosure 12*b* and identical structure in the latter embodiment is indicated by the same reference numerals but with a "b" suffix. Therefore, the enclosure 12*b* will not be described in detail.

A steam drum 116 (FIG. 1) is located above the system 10 and, although not shown in the drawings, it is understood that a plurality of headers are disposed at the ends of the various water-tube walls described above. As shown in general by the reference numeral 118, a plurality of downcomers, pipes, etc. are utilized

to establish a flow circuit for circulating a cooling fluid such as water or steam or a water and steam mixture through these headers, the steam drum **116**, and the various tubed walls, partitions, and heat exchange surfaces, with connecting feeders, risers, and headers being provided as necessary. Thus, water is passed in a predetermined sequence through this flow circuitry to convert the water to steam and to heat the steam by the heat generated by combustion of the particulate fuel material.

For ease of presentation, the operation of the present system will be described with reference to enclosure **12***a*. In operation, particulate material including fuel and sorbent material are introduced into the furnace section **30***a* through the feeder system **38***a*. Alternately, sorbent may also be introduced independently through openings formed through one or more of the enclosure walls. Air from an external source is introduced at a sufficient pressure into the plenum **26***a* extending below the furnace section **30***a*, and the air passes through the nozzles **36***a* disposed in the furnace section **30***a* at a sufficient quantity and velocity to fluidize the particulate material in the furnace section **30***a*. Each nozzle **36***a* is adjusted so that the velocity of the air discharged therefrom increases from right-to-left as viewed in FIG. **1**, i.e., the nozzles **36***a* closest to the front wall **14***a* discharge air at a relatively high velocity while the nozzles **36***a* closest to the partition **24***a* discharge air at a relatively low velocity.

A liftoff burner (not shown), or the like, is provided to ignite the fuel material, and thereafter the fuel material is self-combusted by the heat in the furnace section **30***a*. Combustion of the fuel material generates combustion gases which mix with the air introduced through the plate **22***a*, which mixture is hereinafter referred to as flue gases. The flue gases pass upwardly through the furnace section **30***a* and entrain, or elutriate, a portion of the particulate material.

The quantity of particulate material introduced into the furnace section **30***a* and the quantity of air introduced, via the air plenum **26***a*, through the nozzles **36***a* and into the interior of the furnace section **30***a* is established in accordance with the size of the particulate material so that a dense bed is formed in the lower portions of the furnace section **30***a* and a circulating fluidized bed is formed in the upper portions thereof, i.e. the particulate material is fluidized to an extent that substantial entrainment or elutriation thereof is achieved. Operated in the above manner, the density of the particulate material is relatively high in the lower portion of the furnace section **30***a*, decreases with height throughout the length of the furnace section **30***a* and is substantially constant and relatively low in the upper portions of the furnace section **30***a*. Since the operation in the enclosure **12***b* is identical to that in the enclosure **12***a*, the former will not be described in detail.

As best shown in FIGS. **3** and **4**, the openings **64** in the lower portion of the common wall **60** are sized to permit adequate flow of the particulate material between the furnace sections **30***a* and **30***b* so that the respective heights of the solids in the furnace sections **30***a* and **30***b* section are substantially the same.

Referring again to FIG. **1**, the flue gases passing into the upper portion of the furnace section **30***a* are substantially saturated with the particulate material and pass, via the outlet opening in the upper portion of the rear wall **16***a*, into the cyclone separator **40***a*. The openings **62** (FIG. **3**) in the upper portion of the common wall **60** equalize the gas pressure in the furnace sections **30***a* and **30***b* and thus eliminate any pressure drop across the common wall **60**.

In the separator **40***a*, the particulate material is separated from the flue gases, and cleaned flue gases pass to the heat recovery section **48** for passage across the heat exchange surfaces **50**. The separated particulate material passes from the separator **40***a*, through a dipleg **54***a*, J-valve **56***a*, and conduit **58***a*, and into the recycle section **32***a* as described above.

With reference to FIGS. **2** and **4**, the separated solids from the conduit **58***a* enter the compartment **94***a* of the recycle section **32***a*. Assuming normal operation, the plenum chambers **26***a* and **28***a* selectively distribute the air through the nozzles **36***a* and **98***a*, respectively, to the furnace section **30***a* and the recycle section **32***a*. Each nozzle **36***a* and **98***a* is of conventional design and, as such, includes a control device to enable the velocity of the air passing therethrough to be controlled. During such normal operation, fluidizing air is introduced, via the plenum **28***a*, to the nozzles **98***a* in the compartments **92***a*, **94***a* and **96***a* of the recycle section **32***a*, while the air flow to the manifold **102***a*, and therefore to the nozzles **100***a*, is turned off. Since the two rows of nozzles **98***a* in the compartment **94***a* are directed towards the partitions **88***a* and **90***a*, the particulate material passes from the compartment **94***a* into the compartments **92***a* and **96***a*.

The particulate material mixes and builds up in the compartments **92***a* and **96***a* and thus gives up heat to the water/steam in the tubes **104***a* in those compartments. The cooled particulate material then passes through the openings **106***a* and **110***a* in the partition **68***a* through the channel **70***a* (FIG. **1**), through the openings **34***a* in the partition **24***a*, and back into the furnace section **30***a*.

As shown in FIGS. **3** and **4**, the openings **66** in the common wall **60** are sized to permit adequate flow of particulate material between the compartments **96***a* and **92***b* of the recycle sections **32***a* and **32***b*, respectively, so that the respective heights of the particulate material in the compartments **92***a*, **96***a*, **92***b* are maintained substantially the same.

Since, during the above operation there is no air introduced into the nozzles **100***a* in the compartment **94***a*, very little, if any, flow of particulate material occurs through the compartment **94***a* and opening **108***a*. During initial start up and low load conditions, the fluidizing air flow to the plenum **28***a* is turned off and the air flow to the manifold **102***a*, and therefore to the nozzles **100***a*, is turned on. As a result, the volume of particulate material in the compartments **92***a* and **96***a* slump and therefore seal these compartments from further flow. Thus, the separated particulate material from the conduit **58***a* passes directly through the compartment **94***a* and, after building up to the level of the opening **108***a*, passes through the opening **108***a*, through the channel **70***a*, through the openings **34***a* in the partition **24***a*, and back into the furnace section **30***a*. Since the compartment **94***a* does not contain heat exchange tubes **104***a*, start up and low load operation can be achieved without exposing the banks of tubes **104***a* to the hot recirculating particulate material.

If desired, secondary air may be introduced into the enclosure **12***a* via inlets **80***a* and **82***a*, the secondary air from inlet **80***a* passing through the spaces in the partition **76***a* and through the recycle section **32***a* before exiting through the lower two rows of nozzles **84***a* leading into the furnace section **30***a*. The secondary air

from the inlet **82***a* is prevented from passing into the recycle section **32***a* by the partition **78***a* and therefore passes through the upper two rows of nozzles **84***a* leading into the furnace section **30***a*. The fluidizing air that is introduced into the recycle section **32***a* is controlled to entrain fine fuel particles in the recycle section. In this manner, fine fuel particles of approximately 1 to 10 micrometers in diameter are exposed to the secondary air from the secondary air inlet **80***a* and pass with the secondary air through the nozzles **84***a* into the furnace section **30***a*. The high oxygen content in the latter air promotes the combustion of these entrained fine fuel particles as they pass from the recycle section **32***a*, through the lower two rows of nozzles **84***a* and into the furnace section **30***a*.

Feed water is introduced into the flow circuit described above and is circulated therethrough in a predetermined sequence to convert the feed water to steam and to reheat and superheat the steam.

Also, drain pipes (not shown) may be provided for the furnace section **30***a* and recycle section **32***a* and for each furnace section and recycle section as desired for discharging spent particulate material, in a conventional manner.

The system and method of the present invention have several advantages. For example, in the embodiment of FIGS. **1–4**, the use of two adjacent enclosures sections **12***a* and **12***b* sharing a common wall **60** enables the size of the system **10**, and therefore the load capacity, to be increased without increasing the height of the system. Moreover, the provision of openings **64** and **66** provided in the lower portion of the common wall **60** equalizes the heights of the respective dense beds in the furnace sections **30***a* and **30***b* and recycle sections **32***a* and **32***b*, thus correcting for imbalances in the fuel feed from the feeder systems **38***a* and **38***b*, or the like. Further, since the adjacent enclosures **12***a* and **12***b* are substantially the same, a single control scheme can be utilized which controls the operation in both enclosures. Moreover, the provision of the openings **62** in the upper portion of common wall **60** enables the respective gas pressures in the furnace sections **30***a* and **30***b* to be equalized, thus minimizing or eliminating any lateral loading across the common wall **60** and possible damage. Also, the openings **62** enable a predetermined gas pressure drop to be set across the furnace sections **30***a* and **30***b* and enable the entrainment and circulation to be substantially the same in each furnace section **30***a* and **30***b*. Also, the provision of the openings **62** enables substantially the same combustion environments to be established above the dense bed in both furnace sections **30***a* and **30***b*.

Although the embodiment described above utilizes a single common wall **60** shared between two substantially identical enclosures **12***a* and **12***b*, it is understood that multiple common walls can be used in a similar manner to join additional enclosures. As examples of this, FIGS. **5** and **6** depict alternate embodiments of the present invention in which adjacent and opposing enclosures are joined by common walls.

According to the embodiment of FIG. **5**, two more enclosures **12***c* and **12***d*, which are substantially similar to enclosures **12***a* and **12***b*, are joined with enclosures **12***a* and **12***b*. Enclosure **12***c* is disposed opposite enclosure **12***a* and adjacent enclosure **12***d*, and enclosure **12***d* is disposed opposite enclosure **12***b*. Enclosure **12***a* and enclosure **12***c* share a common wall **120**, and enclosure **12***b* and enclosure **12***d* share a substantially identical common wall **122**. As shown in FIG. **7**, common wall **122** (and common wall **120**) has a plurality of openings **124** in an upper portion for permitting flue gases to pass between the furnace sections joined thereby. The openings **124** equalize gas pressure in the joined furnace sections and thus eliminate any pressure drop across the common wall **122**. The common wall **122** (and common wall **120**) also has a plurality of openings **126** in a lower portion for permitting particulate material to flow between the furnace sections joined thereby. The openings **126** are sized to permit adequate flow of particulate material between the furnace sections joined thereby so that the respective heights of the dense beds in the furnace sections are substantially the same. The common wall **128** between enclosure **12***c* and enclosure **12***d* is substantially identical to common wall **60**. Separators **40***a*, **40***b*, **40***c*, and **40***d* are associated with the respective enclosures **12***a*, **12***b*, **12***c*, and **12***d* in a substantially identical fashion as separator **40***a* is associated with enclosure **12***a* in the embodiment described in detail above. The separators **40***a*, **40***b*, **40***c* and **40***d* function in a substantially identical manner as separator **40***a* in the embodiment described in detail above. The embodiment of FIG. **5** thus functions in the same manner as described above in connection with the embodiment of FIGS. **1–4** while enjoying the added capacity and flexibility of the additional enclosures.

According to the embodiment of FIG. **6**, two additional enclosures **12***e* and **12***f*, which are substantially similar to enclosures **12***a*, **12***b*, **12***c*, and **12***d*, are joined with enclosures **12***a*, **12***b*, **12***c*, and **12***d*. Enclosure **12***e* is disposed adjacent enclosure **12***b* and opposite enclosure **12***f*, and enclosure **12***f* is disposed adjacent enclosure **12***d*. Common walls **130** and **132**, dividing enclosures **12***b* from **12***e* and **12***d* from **12***f*, respectively, are substantially identical to common walls **60** and **128**. Similarly, common wall **134** dividing enclosure **12***e* from enclosure **12***f*, is substantially identical to common walls **120** and **122**. Separators **40***a*, **40***b*, **40***c*, **40***d*, **40***e*, and **40***f* are associated with enclosures **12***a*, **12***b*, **12***c*, **12***d*, **12***e*, and **12***f*, respectively. The embodiment of FIG. **6** functions in the same manner as described above in connection with the embodiment of FIGS. **1–4** and the embodiment of FIG. **5** while enjoying the added capacity and flexibility of the additional enclosures.

Other modifications, changes and substitutions are intended in the foregoing disclosure and in some instances some features of the invention will be employed without a corresponding use of other features. Accordingly, it is appropriate that the appended claims be construed broadly and in a manner consistent with the scope of the invention.

What is claimed is:

1. A fluidized bed combustion system comprising:

an enclosure having a front wall, a rear wall, a first side wall and a second side wall;

a partition extending between said side walls and dividing said enclosure into a furnace section and a recycle section;

means for introducing particulate material including fuel into said furnace section;

means for introducing particulate material into said recycle section;

means for passing particulate material from said recycle section to said furnace section;

a grate disposed in a lower portion of said enclosure for supporting said particulate material in said furnace section and said recycle section; and

means for introducing an oxygen-containing gas through said grate and into said furnace section for fluidizing said particulate material in said furnace section; and

said first side wall having at least one aperture in a lower portion of said side wall and registering with said recycle section so that said particulate material in said recycle section may pass through said aperture.

2. The system of claim 1 wherein:

said first side wall has at least one aperture in a lower portion of said side wall and registering with said furnace section so that said particulate material in said furnace section may pass through said aperture; and

said first side wall has at least one aperture in an upper portion of said side wall and registering with said furnace section so that gases in an upper portion of said furnace section may pass through said aperture.

3. The system of claim 2 wherein:

said second side wall has at least one aperture in a lower portion of said side wall registering with said furnace section so that said particulate material in said furnace section may pass through said aperture;

said second side wall has at least one aperture in a lower portion of said side wall registering with said recycle section so that said particulate material in said recycle section may pass through said aperture; and

said second side wall having at least one aperture in an upper portion of said side wall so that gases in an upper portion of said furnace section may pass through said aperture.

4. The system of claim 2 wherein:

said front wall has at least one aperture in a lower portion of said front wall registering with said furnace section so that particulate material in said furnace section may pass through said aperture; and

said front wall has at least one aperture in an upper portion of said front wall so that gases in an upper portion of said furnace section may pass through said aperture.

5. The system of claim 2 wherein said first side wall is formed by a plurality of spaced cooling tubes connected by continuous fins to form an airtight structure, said apertures in said first side wall being provided by omitting said fins from between portions of said spaced tubes.

6. The system of claim 2 further comprising:

a second enclosure having a second furnace section and a second recycle section, said second enclosure being disposed adjacent said enclosure and sharing said first side wall so that said second furnace section is disposed adjacent said furnace section and said second recycle section is disposed adjacent said recycle section,

said at least one aperture in said lower portion of said side wall and registering with said furnace section also registering with said second furnace section to permit particulate material to pass between said furnace section and said second furnace section,

said at least one aperture in a lower portion of said side wall and registering with said recycle section also registering with said second recycle section to permit particulate material to pass between said recycle section and said second recycle section, and

said at least one aperture in an upper portion of said side wall and registering with said furnace section also registering with said second furnace section to permit gases to pass between said furnace section and said second furnace section.

7. The system of claim 2 further comprising:

a separator disposed adjacent said enclosure for separating particulate material from gases;

means for passing particulate material from said upper portion of said furnace section to said separator; and

wherein said means for introducing particulate material into said recycle section comprises a conduit for passing separated particulate material from said separator to said recycle section.

8. The system of claim 7 wherein said partition has a first portion extending substantially vertically from said grate and a second portion angling upwardly and rearwardly from said first portion and extending to said rear wall.

9. The system of claim 8 wherein said means for passing particulate material from said recycle section to said furnace section comprises:

a second partition disposed between said side walls in said recycle section and extending from said grate to said second portion of said partition to form a channel between said partition and said second partition, an upper portion of said second partition having an aperture for permitting particulate material to pass from said recycle section to said channel, and a lower portion of said partition having an aperture for permitting particulate material to pass from said channel to said furnace section.

10. The system of claim 8 wherein said partition is formed by a plurality of spaced cooling tubes connected by continuous fins to form an airtight structure, said apertures in said partition being provided by omitting said fins from between portions of said spaced tubes.

11. A fluidized bed combustion system comprising:

a first enclosure having a first furnace section;

a first recycle section adjoining said first furnace section;

means for forming a fluidized bed of particulate material including fuel in said first furnace section;

means for forming a fluidized bed of particulate material in said first recycle section;

means for passing particulate material from said first recycle section to said first furnace section;

a second enclosure having a second furnace section;

a second recycle section adjoining said second furnace section;

means for forming a fluidized bed of particulate material including fuel in said second furnace section;

means for forming a fluidized bed of particulate material in said second recycle section;

said first and second enclosure being disposed adjacently and sharing a common wall which divides said first furnace section and said first recycle section from said second furnace section and said second recycle section, said first furnace section being disposed adjacent said second furnace section and said first recycle section being disposed adjacent said second recycle section;

said common wall having at least one aperture extending through an upper portion of said common wall and registering with said first and second fur-

nace sections for permitting gases to pass between said first and second furnace sections to equalize pressure in said furnace sections;

said common wall having at least one aperture extending through a lower portion of said common wall and registering with said first and second furnace sections for permitting particulate material to pass between said first and second furnace sections; and

said common wall having at least one aperture extending through a lower portion of said common wall and registering with said first and second recycle sections for permitting particulate material to pass between said first and second recycle sections.

12. The system of claim **11** wherein said common wall is formed by a plurality of spaced cooling tubes connected by continuous fins to form an airtight structure, each of said apertures in said common wall being provided by omitting said fins from between portions of said spaced tubes.

13. The system of claim **11** further comprising:

a first separator disposed adjacent said first enclosure for separating particulate material from gases;

means for passing particulate material and gases from said first furnace section to said first separator;

means for passing separated particulate material from said first separator to said first recycle section;

a second separator disposed adjacent said second enclosure for separating particulate material from gases;

means for passing particulate material and gases from said second furnace section to said second separator; and

means for passing separated particulate material from said second separator to said second recycle section.

14. The system of claim **13** wherein said first and second separators are cyclone separators.

15. The system of claim **13** wherein said first recycle section is located within said first enclosure and said second recycle section is located within said second enclosure.

16. The system of claim **15** wherein:

said first enclosure comprises a front wall, a rear wall, two side walls, and a first grate for supporting said first and second fluidized beds, said first recycle section being separated from said first furnace section by a first partition, said first partition being disposed between said side walls of said first enclosure, a first portion of said first partition extending substantially vertically from said first grate, and a second portion of said first partition angling upwardly and rearwardly from said first portion and extending to said first rear wall; and

said second enclosure comprises a front wall, a rear wall, two side walls, and a second grate for supporting said third and fourth fluidized beds, said second recycle section being separated from said second furnace section by a second partition, said second partition being disposed between said side walls of said second enclosure, a first portion of said second partition extending substantially vertically from said second grate, and a second portion of said second partition angling upwardly and rearwardly from said first portion and extending to said second rear wall.

17. The system of claim **16** wherein said first and second partitions are formed by a plurality of spaced cooling tubes connected by continuous fins to form airtight structures, and each of said apertures in said first and second partitions are provided by omitting said fins from between portions of said spaced tubes.

18. The system of claim **16** wherein:

said means for passing particulate material from said first recycle section to said first furnace section comprises a third partition disposed between said side walls of said first enclosure and extending in said first recycle section from said first grate to said second portion of said first partition to form a first channel between said first partition and said third partition, an upper portion of said third partition having at least one aperture for permitting particulate material to pass from said first recycle section to said first channel, and a lower portion of said first partition having at least one aperture for permitting particulate material to pass from said first channel to said first furnace section; and

said means for passing particulate material from said second recycle section to said second furnace section comprises a fourth partition disposed between said side walls of said second enclosure and extending in said second recycle section from said second grate to said second portion of said second partition to form a second channel between said second partition and said fourth partition, an upper portion of said fourth partition having at least one aperture for permitting particulate material to pass from said second recycle section to said second channel, and a lower portion of said second partition having at least one aperture for permitting particulate material to pass from said second channel to said second furnace section.

19. The system of claim **18** further comprising:

a fifth partition disposed between said side walls of said first enclosure, a lower portion of said fifth partition angling upwardly into said first recycle section from said first rear wall to said second portion of said first partition, and an upper portion of said fifth partition angling upwardly and rearwardly from said second portion of said first partition of said first rear wall, said lower portion of said fifth partition having at least one aperture; and

a sixth partition disposed between said side walls of said second enclosure, a lower portion of said sixth partition angling upwardly into said second recycle section from said second rear wall to said second portion of said second partition, and an upper portion of said sixth partition angling upwardly and rearwardly from said second portion of said second partition to said second rear wall, said lower portion of said sixth partition having at least one aperture.

20. The system of claim **19** further comprising:

a first plurality of nozzles extending through said second portion of said first partition and into said first recycle section below a point of intersection of said fifth partition with said second portion of said first partition;

a second plurality of nozzles extending through said second portion of said second partition and into said second recycle section below a point of intersection of said sixth partition with said second portion of said second partition;

means for introducing an oxygen-containing gas through said first rear wall and into said first recycle section between points of intersection of said

upper and lower portions of said fifth partition with said first rear wall so that said gas may create oxidizing conditions in said first nozzles for combusting fine particulate material passing through said first nozzles; and

means for introducing an oxygen-containing gas through said second rear wall and into said second recycle section between points of intersection of said upper and lower portions of said sixth partition with said second rear wall so that said gas may create oxidizing conditions in said second nozzles for combusting fine particulate material passing through said second nozzles.

21. The system of claim **11** further comprising:

a third enclosure having a third furnace section;

a third recycle section adjoining said third furnace section;

means for forming a fluidized bed of particulate material including fuel in said third furnace section;

means for forming a fluidized bed of particulate material in said third recycle section;

means for passing particulate material from said third recycle section to said third furnace section;

a fourth enclosure having a fourth furnace section;

a fourth recycle section adjoining said fourth furnace section;

means for forming a fluidized bed of particulate material including fuel in said fourth furnace section;

means for forming a fluidized bed of particulate material in said fourth recycle section;

said third enclosure being disposed opposite and sharing a second common wall with said first enclosure; and

said fourth enclosure being disposed opposite and sharing a third common wall with said second enclosure, and said fourth enclosure being disposed adjacent to and sharing a fourth common wall with said third enclosure;

said second common wall having at least one aperture extending through a lower portion of said wall and registering with said first and third furnace sections permitting particulate material to pass between said first and third furnace sections, and said second common wall having at least one aperture extending through an upper portion of said wall and registering with said first and third furnace sections permitting gases to pass between said first and third furnace sections;

said third common wall having at least one aperture extending through a lower portion of said wall and registering with said second and fourth furnace sections for permitting particulate material to pass between said second and fourth furnace sections, and said third common wall having at least one aperture extending through an upper portion of said wall and registering with said second and fourth furnace sections for permitting gases to pass between said second and fourth furnace sections;

said fourth common wall having at least one aperture extending through a lower portion of said wall and registering with said third and fourth furnace sections for permitting particulate material to pass between said third and fourth furnace sections, said fourth common wall having at least one aperture in a lower portion of said wall and registering with said third and fourth recycle sections for permitting particulate material to pass between said third and fourth recycle sections, and said fourth common wall having at least one aperture in an upper portion of said wall and registering with said third and fourth furnace sections for permitting gases to pass between said third and fourth furnace sections.

22. The system of claim **21** wherein said first recycle section is disposed within said first enclosure, said second recycle section is disposed within said second enclosure, said third recycle section is disposed within said third enclosure, and said fourth recycle section is disposed within said fourth enclosure.

23. The system of claim **21** further comprising:

a fifth enclosure having a fifth furnace section;

a fifth recycle section adjoining said fifth furnace section;

means for forming a fluidizing bed of particulate material including fuel in said fifth furnace section;

means for forming a fluidized bed of particulate material in said fifth recycle section;

means for passing particulate material from said fifth recycle section to said fifth furnace section;

a sixth enclosure having a sixth furnace section;

a sixth recycle section adjoining said sixth furnace section;

means for forming a fluidized bed of particulate material including fuel in said sixth furnace section;

means for forming a fluidized bed of particulate material in said sixth recycle section;

said fifth enclosure being disposed adjacent said second enclosure on a side opposite said first enclosure, and said fifth enclosure sharing a fifth common wall with said second enclosure;

said sixth enclosure being disposed opposite said fifth enclosure and adjacent said fourth enclosure, said sixth enclosure sharing a sixth common wall with said fifth enclosure and sharing a seventh common wall with said fourth enclosure;

said fifth common wall having at least one aperture in a lower portion of said wall and registering with said second and fifth furnace sections for permitting particulate material to pass between said second and fifth furnace sections, said fifth common wall having at least one aperture in a lower portion of said wall and registering with said second and fifth recycle sections for permitting particulate material to pass between said second and fifth recycle sections, and said fifth common wall having at least one aperture in an upper portion of said wall and registering with said second and fifth furnace sections for permitting gases to pass between said second and fifth furnace sections;

said sixth common wall having at least one aperture in a lower portion of said wall and registering with said fifth and sixth furnace sections for permitting particulate material to pass between said fifth and sixth furnace sections, and said sixth common wall having at least one aperture in an upper portion of said wall and registering with said fifth and sixth furnace sections for permitting gases to pass between said fifth and sixth furnace sections; and

said seventh common wall having at least one aperture in a lower portion of said wall and registering with said fourth and sixth furnace sections for permitting particulate material to pass between said fourth and sixth furnace sections, said seventh common wall having at least one aperture in a lower portion of said wall and registering with said fourth and sixth recycle sections for permitting particulate material to pass between said fourth and sixth recy-

cle sections, and said seventh common wall having at least one aperture in an upper portion of said wall and registering with said fourth and sixth furnace sections for permitting gases to pass between said fourth and sixth furnace sections.

24. The system of claim **23** wherein said first recycle section is disposed within said first enclosure, said second recycle section is disposed within said second enclosure, said third recycle section is disposed within said third enclosure, said fourth recycle section is disposed within said fourth enclosure, the fifth recycle section is disposed within said fifth enclosure, and said sixth recycle section is disposed within said sixth enclosure.

25. A method of operating a fluidized bed combustion system comprising the steps of:

providing a plurality of enclosures, each of said enclosures having a furnace section and a recycle section;

introducing particulate material including fuel into said furnace sections;

introducing particulate material into said recycle sections;

introducing an oxygen-containing gas into said furnace sections for fluidizing said particulate material in said furnace sections and for promoting combustion of said fuel to generate combustion gases in said furnace sections, and so that dense beds of particulate material having heights form in said furnace sections, and so that said fluidizing gas combines with said combustion gases to form flue gases which entrain a portion of said particulate material in said furnace sections;

introducing an oxygen-containing gas into said recycle sections for fluidizing said particulate material in said recycle sections so that dense beds of particulate material having heights form in said recycle sections;

equalizing said heights of said dense beds in said furnace sections;

equalizing pressure in said furnace sections; and

equalizing said heights of said dense beds in said recycle sections.

26. The method of claim **25** wherein:

said step of equalizing said heights of said dense beds in said furnace sections comprises permitting particulate material to flow between said furnace sections;

said step of equalizing said pressure in said furnace sections comprises permitting said flue gases to flow between said furnace sections; and

said step of equalizing said heights of said dense beds in said recycle sections comprises permitting particulate material to flow between said furnace sections.

27. The method of claim **26** further comprising:

passing a portion of said flue gases and said entrained particulate material from said furnace sections;

separating said passed, entrained particulate material from said flue gases; and

wherein said step of introducing particulate material into said recycle sections comprises passing said separated particulate material to said recycle sections.

28. The method of claim **27** further comprising removing heat from said separated particulate material in said recycle sections.

29. The method of claim **27** wherein:

said particulate material in said recycle sections includes fine fuel particles; and

further comprising controlling said fluidizing gas introduced into said recycle sections to entrain said fine fuel particles said dense beds in said recycle sections;

passing a portion of said entrained fine fuel particles from said recycle sections to said furnace sections; and

introducing a secondary oxygen-containing gas into said recycle sections above said dense beds so that said secondary gas creates oxidizing conditions for combusting said entrained fine fuel particles as said entrained fine fuel particles pass from said recycle sections to said furnace sections.

* * * * *

UNITED STATES PATENT AND TRADEMARK OFFICE

CERTIFICATE OF CORRECTION

PATENT NO. : 5,299,532
DATED : April 5, 1994
INVENTOR(S) : David H. Dietz

It is certified that error appears in the above-indentified patent and that said Letters Patent is hereby corrected as shown below:

Column 2, line 11, "i" should be --in--.

Column 7, line 30, "liftoff" should be --lightoff-- .

Signed and Sealed this

Eighteenth Day of April, 1995

Attest:

Attesting Officer

BRUCE LEHMAN

Commissioner of Patents and Trademarks